Long Range LiDAR Characterisation for Obstacle Detection for use by the Visually Impaired and Blind

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***Abstract*— Obstacle detection and avoidance is a huge area of interest for autonomous vehicles and, as such, has become an important research topic. Detecting and identifying obstacles enables navigation through an ever changing environment. This work looks at the technology used in self-driving vehicles and examines whether the same technology could be used to aid in navigation for visually impaired and blind (VIB) people. For autonomous vehicles, obstacle detection relies on different sensor modalities to provide information on the vehicles surroundings. A combination of the same sensors placed on a white cane could be used to perform free-space assessment over the whole height of the user and provide additional environmental information not available from the cane alone. This provides its own challenges and advantages. The speeds are much slower when dealing with pedestrians and scanning can be achieved by the movement of the cane. However, the weight and size must be significantly reduced. The full system will be integrated into a smart cane and will consist of four main sensors as well as range sensors. The aim of this work is to report on the characterization of a long range LiDAR (up to 10m) that will be integrated into a smart white cane developed as part of the INSPEX H2020 project.**

Keywords- LiDAR, characterisation, embedded, integrated system, low-power, obstacle detection

I. Introduction

The system described in this paper takes its inspiration from obstacle detection for autonomous vehicles (e.g. LiDAR, radar, IR sensors). In the final system which is intended to be placed on a white cane the various sensors will be integrated and used to create a model of the surrounding obstacles which will be communicated to the user by use of an extra-ocular headphone system. This paper focuses on the long rang LiDAR which will be used to detect obstacles up to 10m. Typically these systems are large in size and power hungry. This is not an issue for the automotive industry but becomes a major obstacle to a portable handheld system. For each of the sensors in this system these issues will be addressed so that the final system will be lightweight and operated for up to 8hrs with a rechargeable battery.

This demonstrator choice may have societal impacts because, according to World Health Organization statistics (WHO), 285 million people are visually impaired world-wide **Error! Reference source not found.**, their number being expected to double by 2040 due to aging and health diseases. Note that only 5% of the VIB persons are fully autonomous in their daily mobility. This mainly originates in the lack of confidence the person has in his/her mobility capabilities [1]. Electronic white canes, able to detect obstacles on the whole person including measurements at high level should improve mobility confidence and reduce injuries, especially at the waist and head.of the user

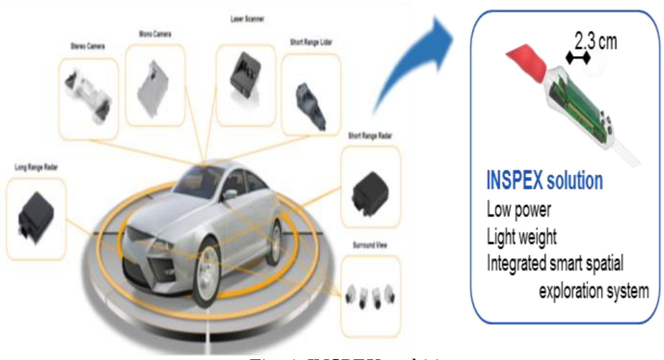

Fig. 1 INSPEX ambition

In this paper a prototype LiDAR system created by SensL is examined. This work aims to characterize this system so that it can be modified for use as part of the INSPEX system for obstacle detection for VIB persons. LiDAR consists of a laser diode which emits a pulse of light. The light hits an object and is reflected. A sensor detects the reflected light and the time of flight is determined. A time to digital converter is used and this information provides the distance information which is accessed through a GUI. Currently the LiDAR system is very large. It requires a peak of 7W of power for a range of up to 25m of detection in indoor lighting conditions. However the pulse duration is very short (150ps) so the system is eye safe. For this work the system was tested using a number of obstacles to determine its range. For indoor obstacles detection was achieved up to the desired 10m. However, it was seen that for outdoor conditions with high brightness conditions the angle of detection is too large and too much optical interference was observed in the measurements.

The system operates as expected up to 5m in both indoor and outdoor conditions. At distances greater than 5m, obstacle detection was achieved indoors reliably. However, in outdoor conditions detection at 10m was affected by the ambient light and measurement could be achieved but not under all conditions. For outdoor conditions the detection angle needs to be reduced so that obstacle detection can be obtained reliably for a distance of up to 10m. The size and weight of the device must also be addressed for use on a cane as there is limited real estate, power requirements and weight are very important when a device is to be held. The initial results are very promising however and it is envisioned that the next generation will have a significant reduction in foot print and improvement in the optics for outdoor use.

The paper objective is to report characterization results of Gen 1 long range LiDAR sensor, brought to the project as a prototype by SensL. This sensor will be integrated in the INSPEX system together with short range LiDar, ultra wideband (UWB) radar and ultrasound range sensors. The INSPEX system requirements will only be met if each range sensor presents power budget, size and weight smaller than the overall ones, with detection range under different environmental conditions in accordance with these requirements.

The paper is organized as follows. Section II summarizes the main requirement for the INSPEX system integrated in a white cane. Section III provides a short description of the long range LiDAR sensor together with its state of the art. Section IV describes the test conditions and provides characterization results. The integration of the initial LiDAR prototype in the smart cane is also discussed together with its compatibility with the system requirements. Section V summarizes the main results and provides possible routes for the LiDAR sensor improvement.

II. Main Requirements of the INSPEX System with Integrated in a White Cane

This system combines a number of sensors to provide information on the obstacles in the path of the user (Ultra wideband RADAR, long and short range LiDAR, ultrasound and range sensors). These sensors each have advantages and disadvantages and together should provide a complete set of data for the surroundings at distances from 0 to 10m. It has been established that ultra-sonic range sensors have limited sensing range (typically, < 3 m) and difficulties of operating on highly reflective surfaces (see e.g. [2]). Laser-based solutions do experience such limitations, but they can be highly sensitive to ambient natural light and identification of transparent or mirror-like surfaces is difficult. RF Radar range sensor performance is affected by the electromagnetic backscattering characteristics of the obstacle, namely its Radar Cross Section (RCS). The RCS of any obstacle is very different from its mechanical response (i.e. to ultrasound waves) or optical response (i.e. to LiDAR). Yamauchi. [3] shows that Ultra WideBand (UWB) radar can be used effectively to detect obstacles under precipitation (rain, snow) and adverse environmental conditions (fog, smoke), thus being fully complementary to LiDAR which is inefficient in such conditions. As a consequence, Ultra-Sound, RF Radar and LiDAR are complementary technologies [2] that must be co-integrated in the obstacle detection system INSPEX is targeting (Fig. 3).

Unfortunately, to the best of our knowledge, no such an integrated system exists because of the size and power budget of existing individual sensors; and the challenges of multiple sensor integration [5]. R&D activity on wearable/portable obstacle detection systems has been performed in the context of drones 10, [6] and robotics [7], and assistive technology for VIB [8][9] and disabled communities [10]. However, these solutions do not perform well on the whole range of environmental conditions encountered by the user in his/her daily life because they integrate a unique range sensing technology. For instance, the majority of smart white canes today only integrate Ultra-Sound sensors, either for commercial products (e.g. [11][12]) or in research prototypes (e.g. [13]), sometimes in conjunction with other modalities [14]). Most of these references do not report power consumption figures, nor system lifetime. Moreover, their exploration range is usually limited to a few meters, which does not allow early notice of potential danger. Other solutions based on cameras can also be found (e.g. [15]). However, the computational cost (and associated power consumption) of image processing does not seem consistent with a portable/wearable low power device. Moreover, acceptability of some advanced solutions (e.g. a horseshoe-shaped device [15]) must be demonstrated.

The INSPEX system must be designed to function under various weather conditions (e.g. rain, snow, sand) over a large temperature range (typically -20°C to 40°C) but also in low visibility conditions (e.g. night, dust, smoke, fog). The organization of sensors must allow detection over the whole person height and larger than his/her shoulder width, cf. Fig. 2.

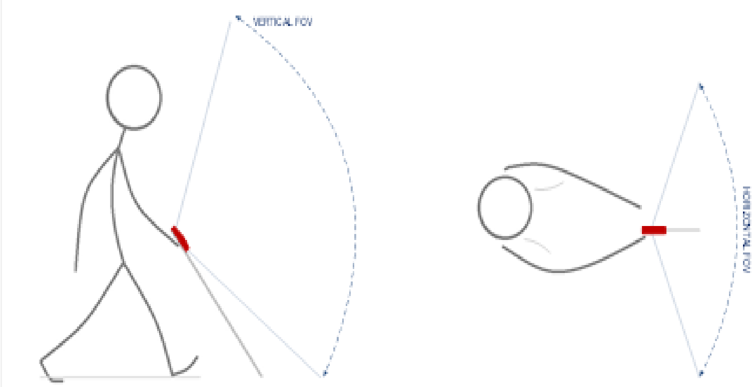

Fig. 2 Vertical (left) and horizontal (right) coverages of the INSPEX system, application to a smart white cane.

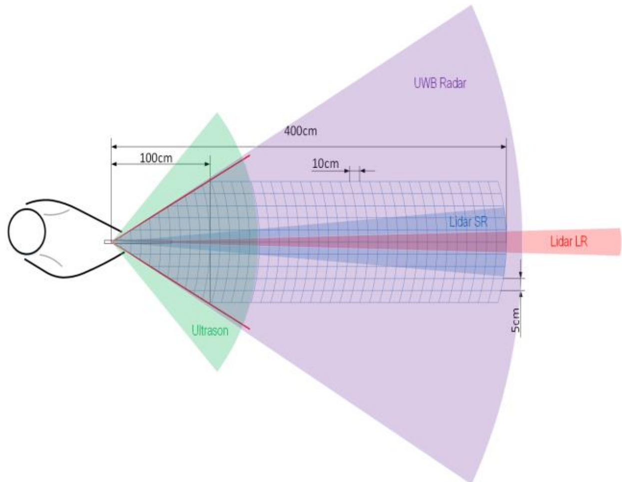

Fig. 3 Co-integration of several range sensors in the context of INSPEX

The INSPEX system should not exceed **2**00g in weight and 100cm^3 in volume. 10 hours of lifetime in continuous use are expected with an initial target for power consumption smaller than 500mW. Information regarding the location of obstacles will be provided *via* an extra-auricular 3D Audio interface.

III. Long Range LiDAR System Discription

A. *Long Range LiDAR Initial Prototype Discription*

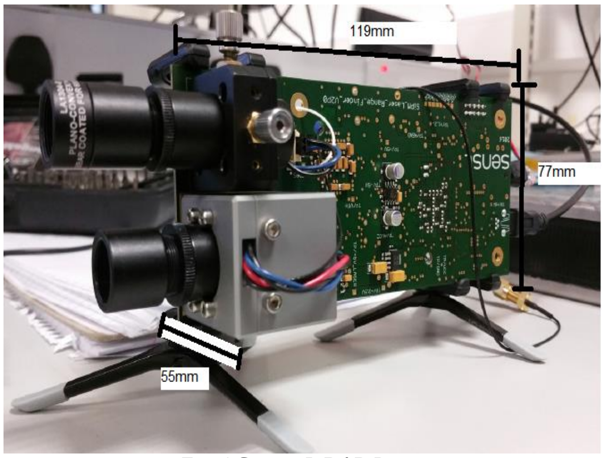

Fig. 4 Current LiDAR Prototype

The LiDAR system operates by emitting a light pulse through a laser diode and measuring the interval until the light is reflected and detected by the sensor using a time to digital converter (TDC). The prototype discussed in this paper is the 25m long range LiDAR developed by SensL for obstacle detection. The device consists of two lenses, one for pulse emission and a second for detection. The pulse is created by a laser diode at a wavelength of 905nm. The emission pulse is

Manufacturer	**System Type**	**Operating λ**	**Frame Rate**	**Accuracy**	**Status**
Ball Aerospace	Imager	1570nm	30Hz	5cm	Commercial
Advanced Scientific	Imager	1570nm	30Hz	<1inch	Commercial
Princeton Lightwave	Imager	920-1440nm	186/70Hz	3.75/8cm	Commercial
Spectrolab – Boeing	Imager	1064-1550nm	100Hz	15cm	Commercial
SPADlab	Imager	300-800nm	100kHz	9.4cm	Commercial
STM	Single Point	VL53L1	N/A	4 m	Commercial
MIT	Imager	Visible	??	8cm	Research
EPFL	Imager	350-800nm	1MHz	3.6cm	Research
Delft	Imager	350-800nm	156kHz	N/A	Research
SensL	Single Point	905nm	N/A	1.32cm	Commercial
SPADNet	Imager	Visible	N/A	0.9cm	Research
Quanergy	Imager	NIR (900 nm)	100 Hz	0.1 m (target)	Commercial
Velodyne	Imager	NIR (900 nm)	30 Hz	± 0.03 m	Commercial
Innoluce	Imager	NIR (900 nm)	??	??	Commercial

Table 1 Current State of the Art

very high power (7W) to obtain detection at the distance required. However the pulse duration is very short (150ps) so that the average power of the device is low and the device is eye safe and suitable for use without protection. The major elements of the device are the control circuitry for the laser diode, the TDC and the FPGA. The FPGA is used to control the circuit and manage the data. The detector collects light and therefore can be effected by ambient light. The laser detection is determined by creating a histogram of the light detected. The laser light from the returning pulse should be the highest power light detected and this appears as a peak on the histogram which then uses this and data to either side of the peak to determine the length of time which elapsed between transmission and detection and therefore the distance of the obstacle which reflected the light. The current prototype is very large because it contains a number of elements which are used for testing but will not be required in future versions of the device.

B. Related state of the art

Thanks to the huge market of the smartphone and the embedded camera, small size and low power LiDAR are the best candidates for the autofocus (AF). These systems tend to focus on short range applications from 0 to 4 m but they have obtained wide market acceptance and are selling in hundreds of millions and are in most cell phones to be released in 2017. For example the VL53L1 from ST Microelectronics [17] has a claimed range of up to 4 m and operates with a highly integrated SPAD sensor, light source, and signal processing electronics. The VL53L1 has no moving parts. Additionally, range finding for automotive applications has increased the development of long range scanning optical systems. An example of this is the Velodyne 16 channel PUK from Velodyne, model number VLP-16 [18]. The VLP-16 relies on more traditional avalanche photodiode (APD) technology, has 16 channels and can image over 360°. The sensors are physically scanned in 360° to generate the image. Roadmap products under development like the Quanergy S3 [19] offer to improve on the Velodyne design by creating solid-state LiDAR which has no moving parts. Other example of companies developing solid-state LiDAR technology are Infineon who recently purchased the MEMS LiDAR company Innoluce [20].

Range and bandwidth are compatible with the Visually Impaired and Blind use cases which are the obstacle detection within a range of 3 to 5 meters. Such a technology is compliant with low power and low size requirements. Conventional light detection and ranging (LiDAR) is a range imaging technique where a laser light signal is launched at a specific target and the returned signal detected and timed by a sensor and readout electronics [CJ01, PRS13]. The timing is used to determine the distance of the target from the laser source and sensor. Imaging systems based on conventional LiDAR use scanning techniques to take individual ranging measurements over a target area to build up a 3D image. If a single point sensor is used then a raster style (both x and y) scanning mechanism can be used. If multiple sensors are used in a linear sensor array (a 1D array of sensors for example) then it is sometimes possible to eliminate one of the degrees of freedom and have a single scanning mechanism. In all cases scanning is required. The main disadvantages of using a scanning technique are: 1/ the time taken to build up the image (repetitive measurements); 2/ the excessive weight/size of the system to include the scanning mechanism; 3/calibration of the scanning mechanism; 4/ reliability of the scanning mechanism. Table 1 provides a review of the current status of LiDAR technology.

IV. Long Range LiDAR Characterization

For full characterization of the LiDAR the device is tested outside of the lab to determine its effectiveness in uncontrolled environments. Since the current prototype is not battery powered the portability of the device is limited

A. Description of the experimental setup

The device is placed on a stand 8.5cm high and connected to the mains and to a computer running a GUI for data visualization. The sensor is placed at known distances from the obstacle and the results are recorded. This can be achieved directly through analyzing the histogram and determining the location of the peak. The software also provides the distance information in meters. The device was tested outdoors so that the environment was not fully controlled. However, since the current prototype is not fully portable the locations for testing were limited. The device was tested for a number of different obstacles common in the outside world including tree branches, steps and signs. The obstacles were tested at 3 and 5m intervals. Typical obstacles tested are shown in Figure 6.

Fig. 5 Device Set-Up

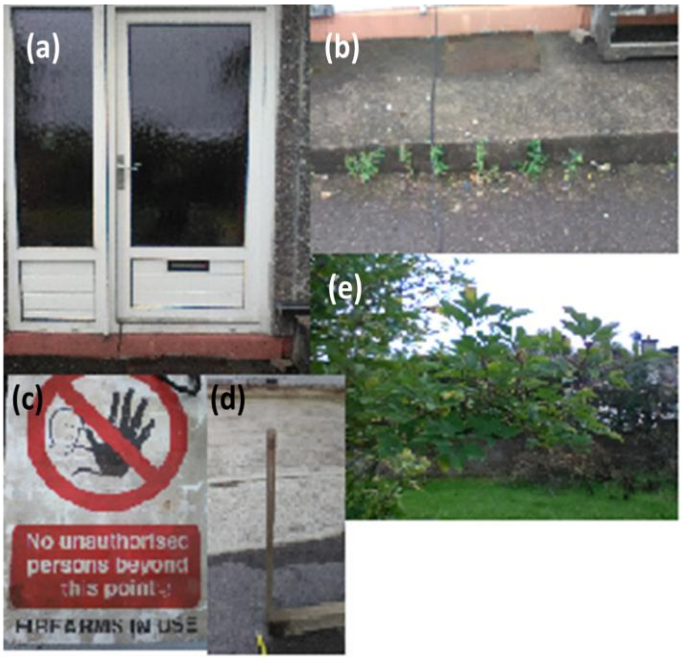

Fig. 6 Typical obstacles. (a) Glass door, (b) step, (c) sign, (d) pole, (e) branch

B. *Characterisation results*

Various obstacles that would be encountered by VIB people in the natural environment were chosen to be detected. Of particular interest are obstacles which are not easily detected or those not detected as early with a white cane. In this case obstacles which are hanging down such as a branch or a sign and obstacles where only a small portion of the obstacle in placed on the ground such as a table. The typical results for obstacles at 3m and 5m are shown in Figures 7 and 8 respectively. As can be seen the reflected laser light is clearly visible above the noise of the ambient light. In this case the branch was tested outside on an overcast day and the table was tested inside a room illuminated by overhead lights. Fig. 9 is a histogram recorded for a sign at 3m distance. Here you can see that a number of peaks are detected around 3m. When reading the distance from the GUI it can be seen that the detector will give values around the expected distance as the pulses return to the detector. The average of these values is recorded and presented in Table 2. Table 2 also shows some of the results obtained for different obstacles. This list of obstacles will be added to as the device becomes more portable so that new obstacles can be detected in situ. Also some devices have been tested for distances up to 10m. However this testing has not been exhaustive and the next round of testing will include characterizing the device for various obstacles up to 10m distance.

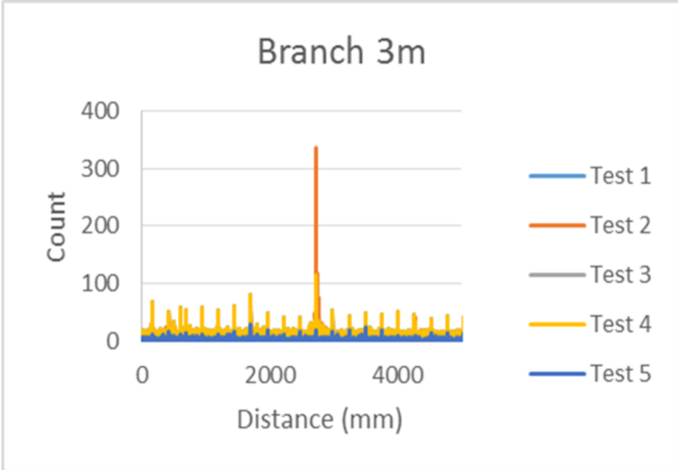

Fig. 7 Histogram Output for a branch 3m from sensor

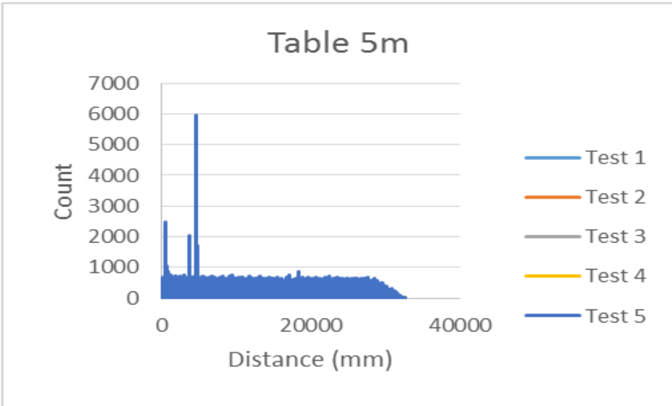

Fig. 8 Histogram Output for table at 5m zoomed out

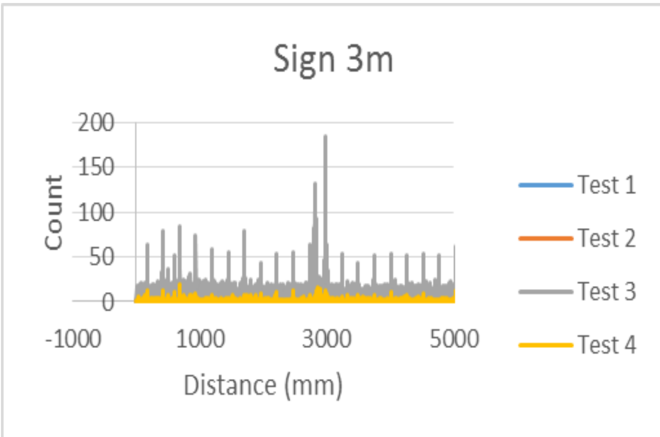

Fig. 9 Histogram Output for table at 3m

C. Discussion

From the results it is seen that consistent detection of the various devices is achieved for 3m and 5m. Further testing is needed for 8m and 10m detection so that the results can be compared. The tests were carried out in overcast weather conditions and more tests must be carried out in different weather conditions to determine if the device will operate at all times. However, to achieve this the portability of the device will need to be addressed as the current version is large and is powered from the mains. Also packaging for the device when it needs to be used in rain should considered. The current results are promising for obstacle detection but the longer distances will need to be fully characterized to give more useful information for a VIB person – particularly when it comes to head height obstacles which could cause serious injury if not avoided. Increasing the portability of the device will aid in both the testing of more varied obstacles and also increasing the testing distance. These are the most important next steps for the current device. The current results do show that the device can be used for medium range obstacle detection and after further testing long range detection will also be shown.

V. Conclusion and Future Work Directions

The final design of the prototype discussed here will be significantly smaller than the current version. The electronics associated with this version include a significant amount of redundancy which was used for test but will not be required in future versions. The circuit will also be optimized to reduce size and increase performance. A particular issue for size reduction is the FPGA which is the largest current circuit element. This FPGA may be reviewed for the next version and a less power hungry but less performant chip found to replace it. Also of issue is the power of the circuit. The laser power required is determined by the detection distance, detection angle and operation and the current laser operates up to 25m which is beyond the requirement for this device then optimization of the laser will contribute to reducing the power requirement. Also the current optics are very large so the next step is also to reduce this to a smaller package possibly using a TO-5 package. This will reduce the size of the optics and also reduced the distance between the emitter and detector which will increase the accuracy of the device.

Further testing of the device for distances up to 10m must also be carried out to fully characterize the current abilities of the sensor and determine possible areas where detection needs to be improved for the next generation of the LiDAR. The LiDAR needs to have line of sight for the device and the angle of detection determines how wide the detection radius is for the device. In the current model the beam is designed such that the angle increases in the x-plane. Since this wide detection angle could be achieved by the movement of the device on a white cane then it is considered for the next version that the beam will increase in the z direction so that head height obstacles can be detected.

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Obstacle	HeightxWidth (cm)	Weather/lighting	Distance (cm)		Sensor distance measurement	Detection
Pole	3x100	Overcast	300		310	Yes
Pole	3x100	Overcast	500		467	Yes
Table	180x72	Indoor	300		302.4	Yes
Table	180x72	Indoor	500		516	Yes
Table	180x72	Indoor	800		824	Yes
Table	180x72	Indoor	1000		1295	Yes
Branch	100x40	Overcast	300		312.2	Yes
Branch	100x40	Overcast	500		517.9	Yes
Sign	20x40	Overcast	300		308.4	Yes
Sign	20x40	Overcast	500		491.7	Yes
Step Up	N/Ax18	Overcast	300		301.4	Yes
Step Up	N/Ax18	Overcast	500		525.4	Yes
Step Up	N/Ax18	Overcast	800		829.8	Yes
Step Up	N/Ax18	Overcast	1000		1032.2	Yes
Step Down	N/Ax18	Overcast	300		311	Yes
Step Down	N/Ax18	Overcast	500		533.6	Yes
Step Down	N/Ax18	Overcast	800		822.7	Yes
Step Down	N/Ax18	Overcast	1000		1041.9	Yes
Glass Door	160x200	Overcast	300		320	Yes
Glass Door	160x200	Overcast	500		535	Yes
Glass Door	160x200	Overcast	800		835.3	Yes
Brick Wall	N/Ax118	Overcast	300		265	Yes
Brick Wall	N/Ax118	Overcast	500		517.9	Yes

Table 2 Results from Obstacle Detection